Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	6437	(134/1 or 134/1.1 or 134/18 or 134/26 or 134/30 or 438/905).ccls.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	ADJ	ON	2005/06/27 14:29
L2	544	l1 and plasma and (hydrogen or '"hsub.2"')	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	ADJ	ON	2005/06/27 14:30

WEST Search History

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DATE: Monday, June 27, 2005

Hide?	Set Name	Query	Hit Count
		DB=USPT; PLUR=YES; OP=ADJ	
☐	L15	L14 and argon and helium	1
☐	L14	L9 and ('h.sub.2') and inert	1
☐	L13	L9 and ('h.sub.2')	1
☐	L12	L9 and ('h.sub.2' and 'he' and 'ar')	0
☐	L11	L9 and ('h.sub.2' with 'he' with 'ar')	0
☐	L10	L9 and ('h.sub.2' with 'he' with 'ar')	0
☐	L9	5935340.pn.	1
☐	L8	L6 and ('h.sub.2' and 'he' and 'ar')	7
☐	L7	L6 and ('h.sub.2' with 'he' with 'ar')	0
☐	L6	5788778	51
☐	L5	5207836.pn. or 5788778.pn.	2
☐	L4	L3 not l2	4
☐	L3	134/1.1.ccls. and plasma and ('h.sub.2' with 'he' with 'ar')	7
☐	L2	438/905.ccls. and plasma and ('h.sub.2' with 'he' with 'ar')	5
☐	L1	438/905.ccls. and plasma and ('h.sub.2' with 'he' with'ar')	0

END OF SEARCH HISTORY

L4: Entry 3 of 4 File: USPT Dec 26, 2000

DOCUMENT-IDENTIFIER: US 6164295 A
TITLE: CVD apparatus with high throughput and cleaning method therefor

Abstract Text (1):
There is provided a CVD apparatus and a cleaning method which can precisely perform cleaning at a high speed, in order to increase the throughput of a CVD apparatus. A film formation gas (e.g., SiH.sub.4 and O.sub.2 gases) is introduced from a source gas supply pipe into a chamber to form a silicon oxide film (SiO.sub.2) on a wafer placed on a susceptor by using a plasma or the like. A thin film (SiO.sub.2) mainly consisting of silicon and oxygen, an imperfect oxide film of silicon, or the like also attaches to a wall surface and the respective surfaces of a window plate, a vacuum seal portion, the susceptor, an electrode, an insulator, an exhaust pipe, and the like in the chamber. An HF-based gas supply system for a cleaning etching gas is arranged to clean the interior of the chamber of the CVD apparatus. Particularly, a film formed with a source gas of Si.sub.x H.sub.2x+2 (x=1, 2, 3) and O.sub.2 is more perfect than an imperfect oxide film (e.g., TEOS) formed with an organic silicon source gas, so that bonding is strong, and the etching rate decreases in plasma cleaning and the like. Cleaning with the HF gas according to this invention is very effective.

Brief Summary Text (3):
CVD (Chemical Vapor Deposition) techniques include thermal CVD, plasma CVD, and photo assisted CVD techniques. A CVD apparatus is one of semiconductor manufacturing apparatuses for growing, on a wafer, a thin SiO.sub.2 film and the like required to fabricate a semiconductor element. In the CVD apparatus, as the thin SiO.sub.2 film is growing on the wafer, a perfect or imperfect oxide film mainly consisting of Si and O attaches to and is deposited on the inner wall surface of a reaction chamber (to be referred to as a chamber hereinafter), an insulator surface, a susceptor or electrode portion, a vacuum seal portion, a window plate, and the like. With increases in thicknesses, these films peel off to attach as particles to the wafer, resulting in a malfunction of the semiconductor element.

Brief Summary Text (6):
(b) Plasma cleaning using CF.sub.4, C.sub.2 F.sub.6, or NF.sub.3

Brief Summary Text (9):
Since the cleaning (etching) effect of plasma cleaning (b) is low out of the plasma region, the cleaning rate decreases on the inner chamber wall and the insulator surface corresponding to the peripheral region of the plasma. Further, an O-ring (vacuum seal portion coupled to the window plate) in and near the plasma may be undesirably corroded to generate particles.

Brief Summary Text (10):
Plasma cleaning (c) has fewer limitations on cleaning portions than plasma cleaning (b), but its cleaning rate is as low as 100 nm/min or lower. In addition, the O-ring and the like are corroded to generate particles.

Brief Summary Text (11):
A thermal oxide SiO.sub.2 film, and an SiO.sub.2 film formed by CVD at a reduced or

atmospheric pressure using a source gas of silane, tetraethoxysilane (TEOS), or the like are mainly used to manufacture a semiconductor device. Particularly, the SiO.sub.2 film formed by plasma CVD is used to insulate aluminum (Al) interconnections because this film is formed at a low temperature of about 400.degree. C.

Brief Summary Text (12):
In recent years, along with a higher integration and higher speed of semiconductor elements, the presence of contaminants contained in the SiO.sub.2 film and particles poses serious problems due to the following reasons. When the SiO.sub.2 film is formed on the semiconductor substrate using the plasma, stainless steel and aluminum members as constituent elements of the chamber become a metal contamination source and are doped in the SiO.sub.2 film on the semiconductor substrate after the interior of the chamber is exposed to the plasma, or the SiO.sub.2 film deposited on the inner chamber wall and the like peels off.

Brief Summary Text (15):
Plasma cleaning is generally performed in the plasma CVD apparatus using CF.sub.4 or the like for a long period of time. As described above, the step of pre-coating the inner chamber wall and the like with an SiO.sub.2 film about several ten nm to 1 .mu.m thick is performed prior to the step of growing a film on an actual wafer. This step is performed to prevent metal contamination of the SiO.sub.2 film on the wafer by the stainless steel and aluminum members in the chamber.

Brief Summary Text (20):
In the plasma cleaning method, however, the protection film (pre-coated film) formed in advance in the pre-coating step is also removed when the film deposited in the chamber is removed. For this reason, this plasma cleaning method has the following problems (a) and (b).

Brief Summary Text (21):
(a) As described above, the cleaning rate changes in and out of the plasma region. At a portion where the cleaning rate is high, the inner chamber wall is exposed early and damaged by the plasma. The damage in the CVD apparatus may become a new cause of generation of particles. Further, consumables inside the apparatus must be frequently exchanged, resulting in a very high cost.

Brief Summary Text (36):
As the third representative feature of the present invention, there is provided a CVD apparatus for growing a silicon oxide film, comprising first introduction means for introducing at least one kind of gas of CF.sub.4, C.sub.2 F.sub.6, NF.sub.3, and F.sub.2 into the CVD apparatus, second introduction means for introducing at least one kind of gas of H.sub.2, H.sub.2 O, and H.sub.2 O.sub.2 into the CVD apparatus, and means for generating a plasma using the gases from the first and second introduction means to perform plasma cleaning with respect to an interior of the CVD apparatus.

Brief Summary Text (40):
As the third representative feature of a CVD apparatus cleaning method according to the present invention, there is provided a cleaning method for a plasma CVD apparatus for growing a silicon oxide film, comprising the step of performing plasma cleaning with at least one kind of gas of CF.sub.4, C.sub.2 F.sub.6, NF.sub.3, and F.sub.2 and at least one kind of gas of H.sub.2, H.sub.2 O, and H.sub.2 O.sub.2.

Drawing Description Text (3):
FIG. 1 is a sectional view showing main part of the system arrangement of a plasma CVD apparatus according to the first embodiment of the present invention;

Drawing Description Text (9):

FIG. 7 is a sectional view showing main part of the system arrangement of a plasma CVD apparatus according to the eighth embodiment of the present invention;

Drawing Description Text (10):
FIG. 8 is a graph showing comparison between etching using both plasma cleaning and HF cleaning and etching using neither plasma cleaning nor HF cleaning;

Drawing Description Text (11):
FIG. 9 is a sectional view showing main part of the system arrangement of a plasma CVD apparatus according to the 10th embodiment of the present invention;

Drawing Description Text (18):
FIG. 16 is a conceptual view showing main part of the system arrangement of a plasma (CVD apparatus according to the 16th and 18th embodiments of the present invention; and

Detailed Description Text (4):
FIG. 1 is a sectional view showing main part of the system arrangement of a plasma CVD apparatus according to the first embodiment of the present invention. Reference numeral 11 denotes a reaction chamber of the CVD apparatus; 11-a, an inner wall surface of the chamber; 12, an insulator; 13, a susceptor and electrode (lower electrode); 14, an electrode (upper electrode); 15, a vacuum seal portion (O-ring); 16, a silica window plate; 17-a and 17-b, source gas supply pipes; 18, a cleaning etching gas supply pipe; 20, an exhaust pipe; and 21, e.g., an automatic pressure regulating valve. A supply system 23 for an HF-based gas as a cleaning etching gas is arranged on the upstream side of the gas supply pipe 18 through, e.g., a valve 22. The gas supply pipe 18 is preferably constituted by a corrosion-resistant member (e.g., a ceramic pipe) in consideration of the supply of the HF-based gas.

Detailed Description Text (5):
In FIG. 1, a film formation gas (e.g., SiH.sub.4 and O.sub.2 gases) is introduced into the chamber 11 through the source gas supply pipe 17-a to form a silicon oxide film (SiO.sub.2) on a wafer placed on the susceptor 13 by using a plasma or the like. A thin film (SiO.sub.2) mainly consisting of silicon and oxygen, an imperfect oxide film of silicon, or the like also attaches to the inner wall surface 11-a of the chamber 11 and the respective surfaces of the window plate 16, the vacuum seal portion 15, the susceptor 13, the electrode 14, the insulator 12, the exhaust pipe 20, and the like.

Detailed Description Text (12):
According to the present invention, particularly a film formed with a source gas of Si.sub.x H.sub.2x+2 (x=1, 2, 3) and O.sub.2 is more perfect than an imperfect oxide film (e.g., TEOS) formed with an organic silicon source gas, so that bonding is strong, and the etching rate decreases in plasma cleaning and the like. Therefore, cleaning with the HF gas according to the present invention is very effective.

Detailed Description Text (13):
In addition, since a nitrogen-doped silicon oxide film (e.g., SiON formed by CVD of TEOS+O3+NH.sub.3 or SiH.sub.4 +O.sub.2 +NH.sub.3) is more strongly bonded, the etching rate further decreases in plasma cleaning and the like. Therefore, cleaning with the HF gas according to the present invention is more effectively performed.

Detailed Description Text (35):
FIG. 7 is a sectional view shoving main part of the system arrangement of the a plasma CVD apparatus according to the above-described eighth embodiment of the present invention. The CVD apparatus of the eighth embodiment is different from that in FIG. 1 in that it comprises a heating mechanism 27 for partially increasing the temperature.

Detailed Description Text (37):

A CVD apparatus cleaning method in consideration of the use of plasma cleaning will be described as the ninth embodiment. Plasma cleaning itself has a low cleaning rate, but exhibits a new effect with HF gas cleaning. HF cleaning of a silicon oxide film utilizes an increase in etching rate upon an increase in concentrations of H and F in the film.

Detailed Description Text (38):
An unnecessary film attached to the inner chamber wall or the like is changed into a film doped with H and F upon CF.sub.4 plasma cleaning or plasma application. The cleaning rate increases synergistically (FIG. 8). Plasma cleaning may be performed at the same time with or before HF cleaning. Plasma cleaning may be performed with the HF gas. Considering the reliability, HF cleaning which may corrode silica, stainless steel, and aluminum members may be performed in the first half, and moderate plasma cleaning may be performed in the second half.

Detailed Description Text (39):
FIG. 9 is a sectional view showing main part of the system arrangement of a plasma CVD apparatus according to the 10th embodiment of the present invention. A reaction is caused by a plasma in a chamber in plasma cleaning to generate HF gas, thereby performing HF cleaning. In FIG. 9, CF.sub.4 gas and H.sub.2 O gas are respectively introduced from gas supply pipes 18 and 17-b into a chamber 11. The same reference numerals denote the same parts as in FIG. 1. With a plasma,

Detailed Description Text (40):
According to the above method, no HF gas is introduced from the outside of the chamber, and the inlet pipe is free from any corrosion. Although CF.sub.4 and H.sub.2 O gases are employed in this embodiment, another combination may be used. For example, at least one kind of gas of CF.sub.4, C.sub.2 F.sub.6, NF.sub.3, and F.sub.2, and at least one kind of gas of H.sub.2, H.sub.2 O, and H.sub.2 O.sub.2 are introduced into the chamber to generate a plasma, thereby generating HF gas inside the chamber.

Detailed Description Text (42):
The gas saturated with H.sub.2 O includes an inert gas such as Ar, He, and Ne, CO.sub.2 gas, O.sub.2 gas, NO.sub.2 gas, and H.sub.2 gas, in addition to N.sub.2 gas. The H.sub.2 O vapor may not be saturated.

Detailed Description Text (54):
To clean a film (about 3 .mu.m thick) mainly consisting of Si and O, which is deposited on the inner chamber wall of the CVD apparatus, cleaning with the HF gas according to the present invention requires only 6 min which is about half the conventional CF.sub.4 plasma cleaning time of about 12 min. Further, the film can be cleaned within about 2 min by performing both cleaning with the HF gas and CF.sub.4 plasma cleaning described in the embodiment. In addition, since cleaning is performed while preventing the pre-coated film from etching and the respective portions in the chamber from corrosion, the throughput (manufacturing efficiency) and service life of the CVD apparatus greatly increase.

Detailed Description Text (56):
As described above, when an SiO.sub.2 film is formed on a semiconductor substrate or the like by plasma CVD in the process of manufacturing a semiconductor device, the plasma impacts on the inner chamber wall. To prevent a metal as a chamber material from mixing in the SiO.sub.2 film upon etching, a SiO.sub.2 film or the like is formed in advance as a pre-coated film on the inner chamber wall.

Detailed Description Text (59):
The use of a gas plasma containing a halogen such as F, or the use of the HF gas is effective in the cleaning step. When an SiOF film is to be deposited on the semiconductor substrate, the pre-coated film can be left, and only the SiOF film deposited thereon can be removed in the subsequent cleaning step even if the

formation temperature of the SiO.sub.2 film as a pre-coated film is not particularly controlled

Detailed Description Text (61):
FIG. 16 is a conceptual view showing main part of the system arrangement of a plasma CVD apparatus according to the 16th embodiment. Reference numeral 31 denotes a reaction chamber of the CVD apparatus; 32, a wafer holder and lower electrode (susceptor); 33, a semiconductor substrate; 34, a resistance heater; 35, an RF power supply; 36, a matching device; 37, a gas inlet; 38, a shower nozzle and upper electrode; 39, a vacuum pump; 40, a resistance heater; and 41, a gas supply valve.

Detailed Description Text (68):
As described above, when the pre-coated film is exposed, cleaning substantially stops because of the difference in quality between the pre-coated film and the deposition film on the pre-coated film. The pre-coated film is so formed as to positively increase the film density while heating the chamber 31 to 100.degree. C. or higher. More preferably, a denser pre-coated film can be formed by heating the chamber 31 to 200.degree. C. or higher. Compared to this pre-coated film, the deposition film formed on the pre-coated film during the manufacturing process is low in density, and contains a large amount of water. Further, a dense pre-coated film can be formed by a method of irradiating ultraviolet rays or a method of exposing the film to a plasma. In this case, although not shown, an ultraviolet irradiation mechanism must be arranged, or conditions for generating a plasma must be set after forming the pre-coated film. The density of the pre-coated film can be changed variously, e.g., only on its surface or as a whole.

Detailed Description Text (72):
Next, the 18th embodiment of the present invention will be described with reference to FIG. 16. This embodiment is related to a plasma CVD apparatus for an SiOF film. After a pre-coated film is formed on the inner wall of a chamber 31 by the same method as in the 16th embodiment, a semiconductor substrate 33 is set on a wafer holder 32. Subsequently, the semiconductor substrate 33 is heated to about 370.degree. C. by a heater 34. TEOS as a source gas, O.sub.2, and NF.sub.3 are simultaneously introduced into the chamber 31 at flow rates of 50 cm.sup.3 /min, 500 cm.sup.3 /min, and 0 to 500 cm.sup.3 /min, respectively, while the internal chamber pressure is kept at 5 Torr. 13.56-MHz RF power of 1 kW is applied to an electrode 38 facing the semiconductor substrate 33 to start a discharge and form an SiOF film.

Detailed Description Text (80):
The embodiments have exemplified many examples using the parallel plate type capacitively coupled plasma CVD apparatus for an SiO.sub.2 film, but a discharge method is not limited to them. A discharged may be induced by any one of an inductively coupled discharge method, a microwave discharge method, a magnetoron discharge method, a discharge method using electron beam bombardment, and a helicon discharge method, or a combination of a plurality of discharge methods.

Detailed Description Text (82):
In addition, the application to the plasma CVD apparatus has been described in each embodiment. The CVD apparatus is not limited to the plasma CVD apparatus, and the present invention can be applied to any CVD apparatus for an SiO.sub.2 film such as a photo assisted CVD apparatus and a thermal CVD apparatus. Further, various changes and modifications can be deemed to lie within the spirit and scope of the invention.

Current US Original Classification (1):
134/1.1

CLAIMS:

12. A method according to any one of claims 4, 6, 7, 8, 9, 10 and 11, wherein the cleaning step uses plasma processing.

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L2: Entry 1 of 5 File: USPT Nov 2, 2004

DOCUMENT-IDENTIFIER: US 6811615 B2
TITLE: Photo-assisted chemical cleaning and laser ablation cleaning of process chamber

Brief Summary Text (9):
Unfortunately, such cleaning operations affect a substrate process system's throughput in a variety of ways. For example, system throughput is reduced by the time involved in performing cleaning operations. In an in situ cleaning process, time is spent evacuating process gases from, and introducing/evacuating the cleaning gases into/from the process chamber. Flow rates, plasma power levels, temperature, pressure, and other cleaning process conditions must also be reset to desired levels after the cleaning process is completed. When a wet clean is performed, opening the process chamber and physically wiping the chamber's interior surfaces results in even more downtime because the process must subsequently be re-stabilized. It is thus desirable to reduce the frequency with which such cleaning operations are performed.

Brief Summary Text (10):
Additionally, frequent cleaning operations tend to increase wear on the process chamber components. For example, in-situ cleaning is typically performed using fluoridated carbons (e.g., CF.sub.4, C.sub.2F.sub.6 and the like) or similar fluorine-containing gases (e.g., NF.sub.3 and the like) due to their highly reactive nature. Unfortunately, exposure to plasmas created from such gases often causes the deterioration of process chamber components. This increased wear can lead to component failure, thereby causing extended downtime, and adversely affecting process system throughput.

Brief Summary Text (18):
Another embodiment of the present invention is a method for cleaning a process chamber, comprising the steps of introducing at least one precursor gas to the process chamber via a section connected to the chamber; applying at least one high power density light beam to the section or directly to the process chamber; and applying a plasma to the process chamber, wherein the plasma activates the precursor gas to generate reactive species, and wherein the high power density light beam(s) assists dissociation of the reactive species, thereby cleaning the process chamber.

Brief Summary Text (19):
Yet another embodiment of the present invention is a method for cleaning a process chamber, comprising the steps of introducing at least one halogen-containing precursor gas to the process chamber via a section connected to the process chamber; applying at least one high power density light beam comprising an incoherent light beam or a laser light beam to the section or directly to the process chamber; and applying a plasma to the process chamber, wherein the plasma activates the precursor gas to generate reactive species, and wherein the high power density light beam(s) assists dissociation of the reactive species, thereby cleaning the process chamber.

Brief Summary Text (20):
Yet another embodiment of the present invention is a method for cleaning a process

chamber, comprising the steps of introducing at least one fluorine-containing precursor gas to the process chamber via a section connected to the process chamber; applying at least one high power density laser beam having a wavelength range from about 190 nm to about 10 .mu.m and an energy density range from about 1 W/mm.sup.2 to about 2 MW/mm.sup.2 to the section or directly to the process chamber; and applying a plasma to the process chamber, wherein the plasma activates the fluorine-containing precursor gas to generate reactive species, and wherein the high power density laser beam(s) assists dissociation of the reactive species, thereby cleaning the process chamber.

Drawing Description Text (4):
FIG. 2 is a schematic diagram of photo-assisted process chamber cleaning with remote plasma source cleaning (RPSC) in accordance with another embodiment of the invention. In this scheme, cleaning gas first flows through the remote plasma source region, so that the gas is activated to generate reactive radicals such as F atoms These active species are then introduced via a section on top of the chamber before reaching the showerhead. High-power light or laser radiation is also applied to this section, which could be of a sheet form or a rectangular section.

Detailed Description Text (6):
The present invention is also directed to a method for cleaning a process chamber, comprising the steps of introducing at least one precursor gas to the process chamber via a section connected to the chamber; applying at least one high power density light beam to the section or directly to the process chamber; and applying a plasma to the process chamber, wherein the plasma activates the precursor gas to generate reactive species, and wherein the high power density light beam(s) assists dissociation of the reactive species, thereby cleaning the process chamber.

Detailed Description Text (8):
The present invention is also directed to a method for cleaning a process chamber, comprising the steps of introducing at least one halogen-containing precursor gas to the process chamber via a section connected to the process chamber; applying at least one high power density light beam comprising an incoherent light beam or a laser light beam to the section or directly to the process chamber; and applying a plasma to the process chamber, wherein the plasma activates the precursor gas to generate reactive species, and wherein the high power density light beam(s) assists dissociation of the reactive species, thereby cleaning the process chamber. Representative examples of the specific aspects of this embodiment are as described supra.

Detailed Description Text (9):
The present invention is also directed to a method for cleaning a process chamber, comprising the steps of introducing at least one fluorine-containing precursor gas to the process chamber via a section connected to the process chamber; applying at least one high power density laser beam having a wavelength range from about 190 nm to about 10 .mu.m and an energy density range from about 1 W/mm.sup.2 to about 2 MW/mm.sup.2 to the section or directly to the process chamber; and applying a plasma to the process chamber, wherein the plasma activates the fluorine-containing precursor gas to generate reactive species, and wherein the high power density laser beam(s) assists dissociation of the reactive species, thereby cleaning the process chamber. The representative examples of the specific aspects of this embodiment are as described supra.

Detailed Description Text (18):
Two schemes may be employed depending on the efficiency and cost-performance ratio. In one embodiment, the light beam is the only energy source for the cleaning gas dissociation. In this case, high power density is required for the high dissociation efficiency. In a second example, regular in-situ plasma cleaning or remote plasma source cleaning (RPSC) is employed for the dissociation of the majority of the cleaning gas. As such, the light beam is only used in assisting the

in-situ plasma cleaning or remote plasma source cleaning to achieve higher dissociation efficiency, a faster clean rate and a reduction in the cleaning gas consumption.

Detailed Description Text (30):
Alternatively, in situ plasma cleaning may be employed for the dissociation of a majority of the cleaning gas, while light beams are used to assist the plasma cleaning. In such systems for cleaning the chamber and the exposed components within the chamber, precursor gases are supplied to the chamber. Then, by locally applying a glow discharge plasma to the precursor gases within the chamber, reactive species are generated. The reactive species clean the chamber surfaces by forming volatile compounds with the process residues on those surfaces. High power density light beams enhance the dissociation and generation of reactive species, thereby achieving a higher dissociation efficiency, a faster cleaning rate and a reduction in the cleaning gas consumption.

Detailed Description Text (31):
Alternatively, the plasma may be provided remotely (FIG. 2). A remote plasma source cleaning system comprises a cleaning gas source connected to a remote activation chamber. The cleaning gas source includes a source of a precursor gas, a flow control mechanism for controlling the flow of precursor gas and a conduit for flowing the gas into the remote activation chamber located outside and at a distance from the process chamber. A power activation source, for example a high-power microwave generator, is used to activate the precursor gas within the remote activation chamber.

Current US Cross Reference Classification (3):
438/905

CLAIMS:

22. A method for cleaning a process chamber, comprising of steps of: introducing at least one precursor gas to the process chamber via a section connected to the chamber; applying at least one light beam to the section or directly to the process chamber, wherein the light beam has a energy density ranging from about 1 kW/mm.sup.2 to about 2 MW/mm.sup.2 ; and applying a plasma to the process chamber, wherein the plasma activates the precursor gas to generate reactive species, and wherein the light beam assists dissociation of the reactive species, thereby cleaning the process chamber.

29. A method for cleaning a process chamber, comprising the steps of: introducing at least one halogen-containing precursor gas to the process chamber via a section connected to the process chamber; applying at least one light beam comprising an incoherent light beam to the section or directly to the process chamber; and applying a plasma to the process chamber, wherein the plasma activates the precursor gas to generate reactive species, and wherein the light beam assists dissociation of the reactive species, thereby cleaning the process chamber.

36. A method for cleaning a process chamber, comprising: introducing at least one fluorine-containing precursor gas to the process chamber via a section connected to the process chamber; applying at least one laser beam having a wavelength range from about 190 nm to about 10 .mu.m and an energy density range from about 1 kW/mm.sup.2 to about 2 MW/mm.sup.2 to the section or directly to the process chamber; and applying a plasma to the process chamber, wherein the plasma activates the fluorine-containing precursor gas to generate reactive species, and wherein laser beam assists dissociation of the reactive species, thereby cleaning the process chamber.

62. The method of claim 58, wherein the carrier gas is selected from the group consisting of HF, N.sub.2, Ar, H.sub.2, and He.

65. The method of claim 63, wherein the carrier gas is selected from the group consisting of HF, N.sub.2, Ar, H.sub.2, and He.

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L2: Entry 5 of 5 File: USPT Apr 11, 1989

DOCUMENT-IDENTIFIER: US 4820377 A
TITLE: Method for cleanup processing chamber and vacuum process module

Abstract Text (1):
A process module having remote plasma and in situ plasma generators, and a radiant heater, which represent three separate energy sources. The three sources can be used singly or in any combination and can be separately controllable.

Brief Summary Text (6):
Ser. No. 790,707, filed 10/24/85, Pat. No. 4,685,999, entitled Apparatus for Plasma-Assisted Etching by Davis, Cecil; Carter, Duane; and Jucha, Rhett;

Drawing Description Text (9):
FIG. 7 shows the plasma reactor of FIG. 6 in the closed position, as it would be during the actual etch process.

Drawing Description Text (11):
FIG. 9 shows an improved version of the process module of FIG. 6, in a sample embodiment which includes the capability for process enhancement by ultraviolet light generated in situ and also the capability is also provided for providing activated species (generated by gas flows through an additional plasma discharge which is remote from the wafer face) to the wafer face. The module is shown in a process station which includes only one module and one load lock, but can also be used in embodiments like that of FIGS. 5A and 5B.

Drawing Description Text (15):
FIG. 13 shows an alternative version of the structure of FIG. 12, without the isolator window which (in the embodiment of FIG. 12) helps separate the gas flows of the ultraviolet source plasma from the process gas flows near the wafer face.

Drawing Description Text (16):
FIG. 14 shows a further alternative version of the structure of FIG. 12, wherein the plasma which provides the ultraviolet source is generated between electrodes which are approximately cylindrical, and wherein capability is also provided for providing activated species (generated by gas flows through an additional plasma discharge which is remote from the wafer face) to the wafer face.

Drawing Description Text (17):
FIG. 15 shows an example of a structure which generates activated species by gas flows through a plasma discharge which is remote from the wafer face, in embodiments like that of FIG. 14.

Drawing Description Text (18):
FIG. 16 shows an example of a module which provides the combined capabilities of plasma bombardment from a plasma in close proximity to the wafer face, and provision of activated species from a remote discharge, and illumination of the wafer face with intense ultraviolet light.

Drawing Description Text (27):
FIG. 23 shows the details of a process module, which provides combined capabilities for high-temperature processing (and cleanup), plasma bombardment, and provision of remotely generated activated species to the wafer face.

Drawing Description Text (28):
FIG. 24 shows a process module, which provides combined capabilities for high-temperature processing (and cleanup), plasma bombardment, provision of remotely generated activated species to the wafer face, and illumination of the wafer face by intense ultraviolet light generated in situ.

Drawing Description Text (36):
FIG. 32 shows a process module with remote and in situ plasma.

Detailed Description Text (28):
The inter-chamber transfer port 30 is covered by an isolation gate 31. Although the gate 31 as shown in FIG. 3 seals the inter-chamber transfer port 30 by making sliding contact. When shaft 580 is rotated (as shown in FIG. 3), the linkage provided drives gate 31 upward (as show in FIG. 3) and covers the port 30. To open the port 30 the shaft 580 is rotated in the opposite direction. If desired the sealing can be performed by a rotated movement. (Again, the absence of sliding contact may be advantageous to reduce internally generated particulates.) The isolation gate 31 over the inter-chamber transfer port 30 can operated by an air cylinder, but a stepper motor could be used in the alternative. Thus, a total of four motors can be used: two which use vacuum feedthroughs, and two which are contained inside the exhaust manifold 36. The arm drive motor is now operated again, to extend the transfer arm 28 through inter-chamber transfer port 30 into the adjacent processing chamber. This is the rightmost position of arm 28 as shown in FIG. 1. The adjacent processing chamber may be any one of many different kinds of process modules, for example, any processing module disclosed herein such as an implanter, a plasma etch, and a deposition module or any other type of process module.

Detailed Description Text (30):
Alternatively, the processing chamber may include a fixture having spaced sloped ledges like the ledges 60 inside the transfer box, or may have other mechanical arrangements to receive the wafer. However, in any case, the arrangement used to receive the transferred wafer 48 must have clearance on the underside of the wafer (at least at the time of transfer), so that the transfer arm 28 can reach in on the underside of the wafer to emplace or remove it. If the wafer support pins 53 are used to receive the transferred wafer, it may be desirable to provide a bellows motion or a vacuum feedthrough in order to provide vertical motion of the wafer support pins 53 inside the processing chamber. Thus, for example, where the processing chamber is a plasma etch or RIE (reactive ion etch) module, a bellows may be provided to move the wafer 48 vertically, for example, onto a susceptor after the transfer arm 28 has been withdrawn out of the way of the wafer 48.

Detailed Description Text (39):
FIGS. 6, 7, and 8 show a single wafer reactor which can be used for reactive ion etching. Many of the process modules described in the present application incorporate at least some of the ideas and advantages of this embodiment, together with additional ideas and additional advantages derived therefrom. (A very similar reactor design can be used for plasma etching, e.g. etching at pressures higher than 100 mTorr. The terms "plasmas etching" and "reactive ion etching" (or "RIE") are sometimes kept distinct in the art, with RIE being used to refer to etching under conditions where plasma bombardment is large, i.e. at lower pressure and with the wafer mounted on the powered electrode. This distinction will not be rigorously observed in the present application. The teachings of the present application are applicable to both plasma and RIE etching as conventionally distinguished, although some of the several features taught by the present application are more

advantageous in the context of RIE etching processes.

Detailed Description Text (41):
FIG. 6 shows a single wafer reactor which can be used for reactive ion etching or for plasma etching. As discussed above, the transfer arm 28 places a wafer onto the wafer support pins 53 (FIG. 4) and then retracts. At this point the whole lower assembly, including the chamber 112, ground electrode 110, process gas distributor 120, base plate 138, and quartz cylinder 114 are moved upward, using, e.g., an air cylinder or a vacuum feed through (not shown). A bellows 124 permits this vertical motion to occur while maintaining a vacuum-tight interface to the interior of the module 104. This vertical motion causes the backside of the wafer resting on the wafer support pins 53 to make contact with the powered electrode 118, and at this point the sliding pin supports 130 which are attached to the underside of the wafer support pins 53 retract slightly against a leaf spring 132. (Other elastic elements could be used in place of leaf spring 132, to assure a small amount of give in the sliding pin supports 130, so that the wafer is not pressed against the powered electrode 118 with too much force.)

Detailed Description Text (44):
In an alternative embodiment, the pins 53 are not mounted on sliding pin supports 130 supported by leaf spring 132, but are fixed. Since the helium bleed port 134 assures good thermal contact between the back side of the wafer and the surface of the powered electrode 118, a tolerance of several thousandths of an inch will still permit good RF coupling of the powered electrode 118 to the wafer 48, and still permit good thermal contact between the powered electrode 118 and the wafer 48. A tolerance of this magnitude should provide enough allowance for thermal expansions of chamber walls, variation in seal thickness, variation in wafer thickness, etc., to still permit reliable sealing of the lower chamber portion to the upper portion. Note that, in this embodiment, the quartz cylinder 114 and quartz piece 116 would usefully be shaped slightly differently, to minimize the lateral spread of the plasma adjacent to the face of the wafer. However, it has been found that utilizing sliding pin supports 130 permits the quartz cylinder 114 to confine the plasma closely near the wafer face 54 as shown in FIG. 7.

Detailed Description Text (46):
The process gas distributor 120 is made of quartz, so that it does not pick up eddy currents from the RF power present. Moreover, since the surface of the quartz is highly insulating, the plasma boundary near the quartz will not have as much voltage nor as much current across it as the plasma boundary near a grounded conductive element would. This means that plasma-assisted reactions near the quartz will not occur at as high a rate as they would near a grounded conductive element, so that deposition is reduced. It should also be noted that quartz is a fairly good thermal insulator, and the temperature of the susceptor may therefore be raised (by radiation from the plasma) to 100 or 200 degrees C. This is advantageous for some processes, since raising the temperature of the distributor will further reduce deposition on it.

Detailed Description Text (47):
Under typical RIE operating conditions (10 to 200 microns of pressure, and 100 to 800 watts of applied power) the generated plasma will fill the chamber between the powered electrode 118 and the ground electrode 110 fairly uniformly. Thus, the process gas distributor 120 protrudes into the densest part of the plasma. The process gas distributor 120 is a ring, of perhaps one-half the diameter of the wafer being processed, with hollow supports which lead down to gas connections 140 (FIG. 6) mounted in the base plate 138. A quick-connect mounting is provided for the quartz process gas distributor 120, so it can rapidly and easily be changed out as desired.

Detailed Description Text (48):
The process gas distributor 120 is usefully spaced away from the surface of the

wafer by only four centimeters, for example. This spacing, and the exact shape of the process gas distributor 120, and the spacing of the gas feed ports 122 on the gas distributor, are not critical. These parameters can be changed if desired, but if modified, they should be selected so that diffusion of process gases and process gas products from the gas feed ports 122 in the process gas distributor 120 provides: (1) diffusion-dominated transport of the process gases and process gas products to the plasma boundary at the face of the wafer 48; and (2) a fairly uniform concentration of process gases and process gas products at the plasma boundary next to the face of wafer 48. For example, the spacing of the process gas distributor 120 away from the wafer face could be anywhere in the range from one to fifteen centimeters.

Detailed Description Text (49):
Under these low pressure conditions, and given the high area ratio between the area of the powered electrode 118 in contact with the plasma (which, in this embodiment, is essentially the same as the area of wafer 48), and the grounded electrode area (which in this embodiment is essentially the area of ground electrode 110, plus the interior area of chamber 112 and the exposed upper area of base plate 138), a high density of plasma bombardment will occur at the face wafer face 54. As is well-known to those skilled in the art, this plasma bombardment assists in achieving desirable anisotropy effects during etching.

Detailed Description Text (72):
FIG. 9 shows an improved version of the process module of FIG. 6, in an embodiment which includes the capability for process enhancement by ultraviolet light generated in situ and the capability is also provided for providing activated species, generated by gas flows through an additional plasma discharge which is remote from the wafer face to the wafer face. The module is shown in a process station 570 which includes only one module and one vacuum load lock, but can also be used in embodiments like that of FIGS. 5A and 5B, where a central handling chamber is combined with plural process modules 104 and one or more vacuum load lock chambers 12.

Detailed Description Text (73):
Note that a particulate sensor 202 (FIG. 9) is explicitly shown connected to the interior of the vacuum load lock chamber 12. This particulate sensor 202 need not be physically located very close to the docking position of vacuum wafer carrier 10, as long as the signal from particulate sensor 202 does provide an indication of the level of particulates present in the interior of the vacuum load lock chamber 12. The particulate sensor 202 is usefully located downstream from the vacuum load lock 12, in the pump out path (not shown). The particle sensor is a commercially available laser particle counter (which detects individual particles) combined with a counter which provides an output signal showing the number of particles counted over a certain time duration. The ultraviolet plasma space 220 is supplied with a gas useful for the production of ultraviolet light, for example, H.sub.2, Ar, or He through ring 576. The frequency of the power utilized to generate the ultraviolet light can be, for example, 100 KHz or 13.56 MHz. The module 570 has a process chamber 218 which can have gas introduced through either a distributor 212 or feed 250. Ozone, for example, could be feed through distributor 212. A transparent vacuum wall 238 allow the radiant heat from a heating module 572 to pass through to wafer 48 below.

Detailed Description Text (74):
The following process can also be used with FIG. 9 and the other process modules which have ultraviolet light and remote plasma capability.

Detailed Description Text (75):
One process which can be used with module 570 is for the deposition of polysilicon utilizing either or both an additional ultraviolet generated in side module 570 (which is directly optically coupled into the process chamber 218) and a remotely

generated plasma from remote plasma chamber 254. A silane gas is introduced into the process chamber. If the remote plasma is not used then the silane gas can also be introduced into chamber 218 through distributor 212. The chamber should be maintained at deposition temperature. After the wafer is disposed with chamber 218, a purge can be performed if desired by utilizing an appropriate gas which is non-reactive with the wafer and the exposed layers thereon, for example, N.sub.2. An example of this process follows: The wafer is placed in the chamber. The chamber is evacuated and purged with N.sub.2 (in general the pressures usable within the chamber are between 0.1 to 750 Torr). A remote plasma is generated within chamber 254 from silane gas. The remote plasma is introduced into the chamber 218 and to the downward facing face 54 of wafer 48. The chamber is heated to the deposition temperature of, for example, 550 to 700 degrees C. Additional ultraviolet energy is coupled into chamber 218 from space 220 by exciting the gas therein, for example, H.sub.2, Ar, or He introduced through ring 576 using a power of 300 watts at a frequency of 100 KHz. The reaction is as follows:

Detailed Description Text (76):
where the light enhances deposition by increasing the molecular excitation level. The gases and heat is turned off and the chamber is again purged, with an appropriate gas, if desired. The wafer is then removed. A cleaning step can then be performed as desired utilizing a remote plasma formed from a mixture of HCl and HBr.

Detailed Description Text (77):
Another useful process is the deposition of silicon nitride. A source of nitrogen is used to generate a remote plasma. Locally generated ultraviolet energy is coupled into the process chamber, as discussed above. A gas mixture of a source of silicon, for example, dichlorosilane (DCS) is introduced into the process chamber and to the face 54 of the wafer. The remote plasma and the ultraviolet energy in combination allow the deposition rate to be raised to an acceptable level. A sample process follows:

Detailed Description Text (80):
3. Generating a remote plasma from a gas mixture of DCS and a source of nitrogen, for example, N.sub.2 or NH.sub.3, is introduced into the process chamber.

Detailed Description Text (101):
14. After removing the wafer from the process chamber, utilizing remote plasma to clean the chamber prior to the next wafer.

Detailed Description Text (103):
Another process, which can be useful for the process module 570 of FIG. 9, is the deposition of silicon dioxide. The wafer is placed into the process chamber. The chamber is evacuated and then purged, if desired, with an appropriate gas, for example, N.sub.2. The pressure can vary between 0.1 to 750 Torr. An oxygen source, for example, N.sub.2 O or O.sub.2, is excited within the chamber 254 to produce a remote plasma. A silicon source, for example, silane or disilane, is introduced into the chamber 218 either from chamber 254 or distributor 212. Ozone is introduced into chamber 218 through distributor 212. The wafer is heated to, for example, between 200 to 500 degrees C. Ultraviolet light is generated with space 220 as discussed above to provide the excitation discussed above. After the deposition is performed, the gas and the heat is turned off and the chamber 218 can be again purged, if desired. After the wafer is removed, the chamber can be cleaned utilizing a remote plasma formed from, for example, CF.sub.4 and O.sub.2. The pressure can be, for example, 0.1 to 750 Torr and the ratio of SiH.sub.4 to O.sub.2 can be, for example, 1 to 5.

Detailed Description Text (104):
One class of embodiments disclosed herein provides a deglaze process wherein the activated products of a source gas flow which includes both a fluorine source gas

species or, alternatively, anhydrous HF and also a large percentage of oxygen are flowed across a wafer surface downstream from a plasma discharge which is remote from the wafer surface. This embodiment has the advantages that a dry deglaze process which does not selectively erode silicon is provided. This embodiment has the further advantage that a deglaze process is readily combined sequentially with a following process step. For example, an in situ deglaze can be used to remove native oxides, and assure a clean interface for succeeding deposition steps. The process module 570 shown in FIG. 9 can be used without actuating the ultraviolet light or in the alternative another process module could be constructed without the space 220, ring 576, and the other components associated with the production of ultraviolet light in space 220.

Detailed Description Text (106):
Thus, the teaching of the present application in this respect is that a very high oxygen fraction can advantageously be used to perform deglaze, using a gas flow which has passed through a remote discharge. The introduction of this high fraction of oxygen serves to enhance selectivity by lowering the etch rate of polysilicon. These gas flows would not work as well without the remote plasma, since the additional plasma bombardment would not permit as high a selectivity.

Detailed Description Text (120):
The process gas distributor 212 is a ring, of perhaps one half the diameter of the wafer 48 being processed, with hollow supports which lead to the process piping 216. It is situated several, e.g. four, centimeters from the wafer 48. The exact dimensions of the process gas distributor 212 are not critical. These parameters may be changed if desired, but if modified, they should be selected so that a fairly uniform concentration of process gases and process gas products occurs over the entire wafer face 54. For example, the spacing of the process gas distributor 212 away from the wafer 48 could be anywhere in the range from 1 to 15 centimeters. The process gases provided through the process gas distributor 212 may be of several different types, including mixtures which include active species generated by a remote plasma.

Detailed Description Text (121):
The reaction of these process gases with the thin film materials on the wafer face 54 is enhanced by the ultraviolet light emitted by the in ultra-violet plasma space 220 located below top chamber 218. A second flow of process gases is provided from orifices 222 supplied by the piping 230 into the ultraviolet plasma space or lower chamber 220, wherein a plasma is generated by RF power applied to front electrode 224. The gas suppled can be, for exaple, H.sub.2, Ar, or He. The front electrode 224 is perforated to permit passage of ultraviolet light, but alternatively it may be made with a composition and thickness to be transparent to ultraviolet. Ground electrodes for this plasma are provided by structural metal elements and by the metal walls 228 of the process module. The frequency of the power applied to the electrodes to produce the ultraviolet light can be, for example, 100 KHz or 13.56 MHz. Quartz baffle 232 which in this embodiment is approximately H-shaped in cross section, and has an approximately cylindrical outer surface, separates the gas flows in the ultraviolet plasma space 220 from those in the top chamber 218. Thus, the two chambers 218 and 220 not only have separate gas flows, with top chamber 218 being exhausted through openings 234 between the top of baffle 232 and wafer 48, and the ultraviolet plasma space 220 being exhausted through openings 236 between the bottom of baffle 232 and quartz plate 592. Chamber 218 and space 220 may optionally even be operated at different pressures as long as the pressure differential does not lead to back-flow in the exhaust space.

Detailed Description Text (122):
After the wafer has been positioned on the three support fingers 214 and the module has been closed, power can be applied to the front electrode 224 to generate a plasma, and a gas appropriate for the generation of a ultraviolet plasma is admitted to the ultraviolet plasma space 220 through piping 230. Appropriate gases

include N.sub.2, H.sub.2, O.sub.2, and many other species. The particular gas can be chosen to match the ultraviolet spectrum desired in a particular application. The ultraviolet-source plasma can be generated by using an appropriate gas or mixtures of appropriate gases and appropriate pressures with greater than a minimum power for the particular chamber configuration and structure, for example, 50 watts.

Detailed Description Text (125):
Optionally, if complete separation of the gas flows is not necessary, and especially if very short wavelength operation is desired, the member 239 can be made perforated rather than solid, or can be omitted entirely. This is shown in FIG. 13. The process module 600 is similar to process module 590 of FIG. 12. The gas distributor 602 is similar to distributor 212 of FIG. 12. The quartz baffle 604 is a cylindrical shape (shown as two rectangles in FIG. 13). The process gas to the top chamber 605 is through gas distributor 602 and the ultraviolet plasma space 607 is through piping 609. The front electrode 612 is similar to front electrode 224 in FIG. 12. However, now the process gas in the space 605 can mingle with the process gas in the chamber 605 because the crossbar in the quartz baffle 232 (FIG. 12) is not present in quartz baffle 604.

Detailed Description Text (126):
FIG. 14 shows a process module 620 somewhat similar to process modules 590 (FIG. 12) and 600 (FIG. 13). In FIG. 14, the plasma in the ultraviolet plasma space 220 is driven by two electrodes 244 and 246 which are shaped approximately as concentric cylinders. In addtion, gas distributor 248 in the ultraviolet plasma space 220 is different form the piping 230 in FIG. 12. The quartz baffle 232 in FIG. 14 is H-spaced. Also process module 620 includes a third gas feed 250, which can be used to provide species generated by a remote plasma, as will be discussed below. The gas feed 250 is in addition to gas distributor 212 which is a ring in the top chamber 212 and feed 256 which provides gas into ultraviolet plasma space 220. Further, a susceptor 252, which is RF powered in place of the transparent vacuum wall 238, so that a plasma can be generated in proximity to the wafer face 54. The electrode 244 forms a slip-fit with the feed 250. This slip-fit is not sealed but merely vented downward.

Detailed Description Text (127):
In this application, when a plasma is referred to as being "in proximity" to a wafer, it is meant that the plasma is sufficiently close to the wafer that the DC bias across the dark space at the edge of the plasma induces significant plasma bombardment of the wafer face. The degree of bombardment will be more or less in accordance with the amount of DC bias, which is controlled by pressure, power levels, and, to some extent gas flow composition.

Detailed Description Text (128):
Thus, FIG. 14 shows a separate feed path being provided for activated species generated by a plasma which is remote from the wafer face 54. in this class of embodiments, a process module is configured so that an integrated circuit wafer 48 can be exposed to activated species generated by a first plasma which is separate from the wafer but is in the process gas flow stream upstream of the wafer 48, and also exposed to plasma bombardment generated by a second plasma which has a dark space which substantially adjoins the surface of the wafer. The in situ plasma is relatively low-power, so that the remote plasma can generate activated species, and therefore the in situ plasma power level and frequency can be adjusted to optimize the plasma bombardment energy.

Detailed Description Text (129):
In particular, the embodiments described derive special advantages from the combination of a remote plasma in the gas feed with a low-power plasma in situ. The use of a remote plasma means that a high density of activated species can be provided at the wafer surface, and the use of the low-power plasma in situ means

that sufficient plasma bombardment can be provided to cause anisotropic etching, while limiting the plasma bombardment energy and flux to only that necessary to induce the desired degree of anisotropy. This advantageously permits the damage which can be caused by excessive plasma bombardment energy can be readily avoided. This also advantageously permits the chemistry of the reaction to be fine-tuned. It is desirable to have the plasma bombardment shift the surface chemistry enough to provide anisotropy, but two other primary constraints on any plasma etching process are selectivity and control of extraneous deposition, and the choice of a chemistry to optimize all of these conditions may be very constrained. The ability to independently optimize bombardment conditions provides advantages in developing optimized chemistries, as some of the specific examples discussed below demonstrate. Moreover, the ability to provide a high density of activated species under low-bombardment conditions means that processes can be performed at high throughput under low-bombardment conditions, which was not readily achievable prior to the process modules disclosed herein. Another advantage of using a low-power plasma for the in situ plasma is that wafer heating (which degrades the selectivity to resist) can be minimized.

Detailed Description Text (130):
In a typical usage, the remote plasma will be operated at 300 W or more, and the in situ plasma will be operated at 100 W or less; however, it may be advantages to operate at higher powers, for example, with Aluminum doped with Copper films. Thus, it should be understood that the remote plasma can be operated at four times or more the total power level applied to the in situ plasma. In other alternative versions, the in situ plasma may operated at power levels as low as 25 W. The advantage of reduced plasma bombardment energy is partially independent of the attainment of low power. Thus, the in situ plasma can be operated at a DC bias of 250 V or less, for example, a typical level can be within the 25 to 1000 Volts range.

Detailed Description Text (131):
FIGS. 9 and 32 show an overview of a process module with this capability. In FIG. 9, the remote plasma chamber 254 is connected to the process module by a quartz outlet tube 256.

Detailed Description Text (132):
FIG. 15 shows a remote plasma chamber. A magnetron 264 which, e.g., operates at 2.45 GHz, is directly coupled to a resonant cavity 260 which, e.g., is made of anodized aluminum, and has dimensions of about 1.5 by 3 by 9 inches. A gas input tube 266 is connected to one or more mass flow controllers, to provide a desired flow of process gases, and leads into a gas passage 270 which runs through the resonant cavity 260 and leads into the quartz outlet tube 256. It then passes through a shielded volume which protects against RF leakage out of the cavity. Since the quartz used has an outer diameter of less than a quarter-wavelength, e.g., about 1 inch in this example, which is a shield 268 of the order of one wavelength (or more) long will provide reasonable isolation. The shield 268 extends around the quartz outlet tube 256 and usefully around the whole length of the outlet tube 256, up to the point where it enters the reactor module. A tuning stub 272 permits tuning the cavity to resonance. A nitrogen purge is preferably supplied to the interior of the resonant cavity 260, to prevent ozone generation. Cooling lines (not shown) can also be useful. The outlet tube would be connected to, for example, the gas feed 250 (FIG. 9).

Detailed Description Text (134):
Note that the power efficiency of the remote plasma will be affected by the volumetric ratio of the gas passage 270 to the interior of the resonant cavity 260. Thus, the gas flow passage 270 could be made, instead of the roughly cylindrical shape shown, be modified to have a shape which filled up more of the volume of the cavity.

Detailed Description Text (137):
This has the advantage that the sensitivity of the RF system to loading variations caused by changing process conditions is greatly reduced. This has the further advantage that one RF power source can be coupled to more than one remote plasma generation cavity, if desired.

Detailed Description Text (138):
In the embodiment shown in FIG. 9, the quartz outlet tube 256 is connected to the third gas feed 250, like that shown in FIG. 14 by a non-contact slip fit joint 258. This loose slip fit will permit some of the gas feed to leak out directly into the exhaust space during processing, but this is only a minor problem. The advantage of using a slip fit here is that it accommodates the vertical motion of the process chamber while still permitting essentially the whole path of the gas flow from the remote plasma chamber 254 to be conducted through quartz tubing. As discussed above, the vertical motion serves to open and close the process chamber for wafer insertion and removal. This has been found to be a useful feature in practice since many of the activated species generated by the remote plasma will be very active. These active species include radicals such as Oxygen, quasi-stable molecular species such as oxy-halogen compounds, molecules in quasi-stable states with high electron energies, and especially close to the plasma, a significant fraction of ionized species. The tube used to carry this flow should be both as inert as possible in order to resist attack and be s pure as possible to minimize contamination of the wafer by species which may be removed from the tube walls by the flow of the activated species. Quartz meets both of these criteria for most sources. If the gas flows to be used include fluorine sources the tubing can be made of sapphire, or sintered alumina or copper. Additionally, depending on the process chemistries used, it may be simpler to use quartz if the erosion of the quartz outlet tube 256 and the modification of the chemistry in the gas flow can be tolerated in the particular process being run.

Detailed Description Text (139):
FIG. 16 shows details of another process module 630 which in many respects is similar to that shown in FIG. 14. A wafer 48 is held against a conductive susceptor 300 which may be of aluminum or optionally of silicon if it is useful to modify the process chemistry (e.g. to create a fluorine-deficient plasma near the wafer face 54. The susceptor 300 is located above the wafer 48 with the top chamber 218 located between the wafer 48. The susceptor 300 is cooled by passages 302. If desired susceptor 300 can be heated through passages 302 or by utilizing heater rods (not shown) passing through susceptor 300. The wafer 48 is held against susceptor 300 by the three support fingers 214 in FIG. 16 with its face 54 facing downward away from susceptor 300.

Detailed Description Text (140):
A process which can be performed in the process modules with ultraviolet light generation and remote plasma capability as disclosed herein, for example, 630 is the deposition of conductive films. Conductive films can be produced by reducing or decomposing metal organic compounds with remote microwave activated species. For example, Zn, Al, In or Pb films can be produced by reacting metal organic compounds such as dimethylzinc, trimethylaluminum, trimethylindium or tetramethyllead, respectively, with radicals such as hydrogen or argon. In a sample embodiment, a silicon or HgCdTe substrate (wafer) is transferred into the process chamber. The chamber is evacuated to a pressure of less than 10.sup.-6 Torr. The chamber is then purged with an appropriate gas, for example, hydrogen, which passes into the process chamber through the microwave cavity at, for example, 100 sccm, if desired. The chamber is then brought to a pressure of 0.3 Torr. The substrate is heated to 50 degrees C. Dimethylzinc is introduced into the chamber through distributor 212 at, for example, 6.6 sccm. Active hydrogen radicals are then generated in the remote microwave cavity at, for example, 6 watts, and are introduced into the chamber through feed 250 to mix the dimethylzinc to produce metallic zinc which deposits onto the substrate and methane, which is pumped from the process chamber.

Zn films are produced at 60 Angstroms/minute with 25.times.10.sup.-6 Ohm-cm electrical resistivity.

Detailed Description Text (141):
A process which can be used with the process module 630 as well as the other process modules with in situ ultraviolet energy generation capability is to grow native oxides on HgCdTe. After the wafer is disposed in process chamber 218 and the chamber is closed, the chamber is evacuated to a desired low pressure, for example, 0.05 Torr. A purge of the chamber can be performed if desired using an appropriate gas, for example, O.sub.2 or an inert gas. A remote plasma generated from a source of oxygen, for example, O.sub.2 or N.sub.2 O, is introduced into chamber 218 to perform a cleanup if desired. The remote plasma is shut off. The chamber is evacuated and purged with O.sub.2 or an inert gas, if desired. Ultraviolet light is generated within space 220 and coupled into chamber 218. The ultraviolet light provides the required excitation of the gases within chamber 218. The ultraviolet light is maintained for an appropriate period of time, for example, 1 hour. The chamber is then evacuated and purged with an appropriate gas, for example, N.sub.2. The chamber is then opened and the wafer 48 removed.

Detailed Description Text (142):
Another process which can be utilized with the process modules disclosed herein with ultraviolet light and remote plasma capability, for example, module 630. The wafer is transferred into the process chamber and the chamber closed. A purge with an appropriate gas, for example, N.sub.2 can be performed. A remote plasma is generated from N.sub.2 O and introduced into chamber 218 through feed 250. A silane gas, for example, SiH.sub.4 is introduced into the chamber through distributor 212. Ultraviolet light is produced within space 220 and coupled into chamber 218. It will be absorbed in part by the N.sub.2 O gas in chamber 218. After the deposition is completed, a cleanup operation can be performed, if desired, by utilizing a remote plasma generated from SF.sub.6.

Detailed Description Text (143):
A process gas distributor 212 provides process gases to the top chamber 218 near the wafer face 54. Another process gas distributor 306 provides gases to the ultraviolet plasma space 220 wherein a second plasma, remote from the wafer face 54, is optionally generated by applying RF power to front electrode 224. The species flowed through distributor 306, and the power level applied to front electrode 224, are chosen to illuminate the wafer face with the desired wavelength and intensity of ultraviolet light. The quartz baffle 232 directs the gas flow out of top chamber 218 and ultraviolet plasma space 220 so that the gas flow through the ultraviolet plasma space 220 does not contaminate top chamber 218, which is a similar gas flow to that shown in FIG. 12. The third gas feed 250 provides a gas flow which has been activated by a remote plasma chamber to top chamber 218 near the wafer 48. Voltage for the in situ plasma is applied to susceptor 300.

Detailed Description Text (145):
The deposition of sulfide, selenide, and telluride films such as CdS, ZnS, PbS, CdSe, ZnSe, and other II-IV combinations can be produced by utilizing metal organic compounds and sulfide or selenide gases. The organometallic compounds (metal organic) can be, for example, from the group of dimethyltellurium, dimethylzinc, trimethyaluminium, tetraethylead. The sulfide can be, for example, hydrogen sulfide and the selenide gas can be, for example, hydrogen selenide. The required excitation can be provide by either or both a inert gas actuated remote plasma chamber 254 introduced into the process chamber or ultraviolet light generated in space 220 which is coupled into the process chamber. The susceptor 300 can be heated by utilizing heater rods (not shown) passing through the susceptor. It is also possible to dope the deposited film such as ZnS doped with PbS. For example, a mixture of tetraethylead and dimethylzinc is introduced into the chamber through one distributor 310 and hydrogen sulfide is introduced through a second distributor 312 to produce a mixture of ZnS and PbS.

Detailed Description Text (179):
The process module shown in FIG. 22 has separate energy sources for internal remote microwave plasma generation. RF in situ plasma generation, and radiant heat applied to the same process chamber within the module. The energy sources can be separately controlled either singly or in any combination. The process module provides dry in situ cleanup, high temperature native oxide removal, enhanced film deposition utilizing Radiant Heat. It is also capable of low temperature epitaxial film growth with a remote plasma source combined with radiant heat. Furthermore, it is capable of dry etch, including isotropic and anistropic processes, by using in situ RF and remote plasma in combination. Pre-etch, etch, and post etch processes, direct react and/or rapid thermal processes can also be performed. The process module can, therefore, sequentially perform several different process without moving the wafer.

Detailed Description Text (180):
As shown in FIG. 23, a wafer 48 is shown below a transparent vacuum wall 238 which is located above and spaced a short distance away. A purge gas line 352 is provided to supply gas to the face of wafer 48 which is closest to wall 238. The arrangement of the wafer 48, wall 238, and the heating module is similar to that in FIGS. 21A and 21B. However, in FIG. 23 a silicon electrode 670 is provided between wall 238 and wafer 48. It is the silicon electrode which will be heated directly and the wafer will be heated by thermal conduction. The silicon electrode 670 is connected around its edge to a RF conductor ring 672. Voltage for the in situ plasma close to the face 54 of wafer 48 is supplied to silicon electrode 670 through RF conductor ring 672. The wafer 48, silicon electrode 670, and RF conductor ring 672 are all electrically coupled. FIG. 23 shows a process module 675 which can have both remote (supplied by a gas distributor such as feed 250 in FIG. 16) and in situ plasma (through a gas distributor such as distributor 212 in FIG. 16).

Detailed Description Text (181):
FiG. 23 has four separate energy sources, internally generated ultraviolet energy, remote MW (Microwave) plasma generation, RF in situ plasma generation and radiant heat. Each source is separately controllable and can be used singly or in any combination. Process module 675 can provide dry in situ cleanup. Process module 675 can be used for high temperature native oxide removal, enhanced film deposition utilizing ultraviolet light and radiant heat simultaneously, or any other combination of energy sources desired, low temperature epitaxial film growth with remote MW (Microwave) plasma source combined with radiant heat, or any other combination of energy sources desired, dry etch, including isotropic and anisotropic processes by using in situ RF and remote MW (Microwave) plasma in combination, or any other combination of energy sources desired (Pre-etch, etch, and post etch processes, and direct react and/or rapid thermal processes).

Detailed Description Text (182):
The process module 680 shown in FIG. 24 is similar to process module 675 of FIG. 23 but with the inclusion of an additional source of ultraviolet light. The lamp module 682 is located above transparent vacuum wall 238. A wafer 48 is shown located below wall 238. A silicon electrode 670 is located between wall 238 and wafer 48. The silicon electrode 670 is spaced from wall 238 and in contact with wafer 48. A RF conductor ring 672 is in contact with the silicon electrode 670 to supply RF power for the formation of in situ plasma adjacent face 54 of wafer 48 in top chamber 212. Gas purge feed 352 performs the same function as described above. Remote plasma is provided through feed 250. Process gas distributor 212 provides process gas adjacent the face of the wafer 48. Quartz baffle 232 is H-shaped in cross-section. Fingers 214 support the wafer 48 against electrode 670. Gas distributor 248 supplies gas for ultraviolet plasma space 220. Electrodes 684 and 685 provide arranged along the inner and outer vertical walls of space 220 provide the necessary voltage for the formation of plasma within space 220. In general, the lower portion of the module 680 is similar to module 620.

Detailed Description Text (183):
One process which has been successfully demonstrated permits etching copper-doped aluminum (Al:Cu) films, for example, heavily copper-doped aluminum. RF power is used to generate a plasma and provide plasma bombardment at the wafer face, and the feed gas mixture includes BCl.sub.3, chlorine, and a hydrocarbon source (e.g., an alkyl, such as methane). Depending on the underlying material, a post-etch stage at lower pressure may be used to remove low-volatility residues.

Detailed Description Text (186):
While this embodiment provides tremendous advantages, however, another embodiment provides yet further advantages. The reactor used is one like that shown in FIGS. 23 and 24, which permits both radiant heating and plasma bombardment to be applied to the wafer face. During the etch, the wafer is heated to (e.g.) about 200 C. which prevents copper residues from remaining in place.

Detailed Description Text (187):
A further advantageous use of the radiant heating capability in this embodiment is to enhance removal of residues from the chamber walls. For example, a very efficient chamber cleanup can be performed, after the wafer has been removed, by heating the susceptor to a significantly higher temperature than the processing temperature (e.g. 700 C.). Since the processing chamber is so small, the chamber walls will all be at least somewhat thermally coupled to the susceptor by radiant heat transfer. A feed gas which will produce very active dissociation products in a plasma can be flowed in, and the combination of the high temperature and the active species will remove residues very fast. Suitable feed gases would inlcude a chlorine source such as BCl.sub.3, or a fluorine source such as SF.sub.6.

Detailed Description Text (189):
FIG. 25A shows an overview of a module for edge-preferential processing for photoresist edge bead removal and for simultaneous photoresist bake, but the concepts described here are also applicable to systems for accomplishing other process steps. FIG. 25A shows a process module 690 which is connected in this embodiment by a quartz outlet tube 256 to a remote plasma chamber 254 which generates activated species in the process gas flow, as discussed above. A conical baffle 400 is used to provide enhanced reaction rates at the edge of the wafer. The baffle 400 and the support 692 for a channel which is V-shaped in cross-section. The gas from feed 250 connected to tube 256 is directed upward and outward by the channel formed between the baffle 400 and support 692. The gas exits the channel near the circumference 49 of wafer 48. The wafer 48 is located between the top of baffle which has its cone pointed downward and a transparent vacuum wall 238. A heating module 694 is located above the wall 238.

Detailed Description Text (191):
In FIG. 25B, the gas flow of activated species from remote plasma chamber 254 (FIG. 25A) is connected to a funnel shaped gas distributor 416 by a slip-fit joint 258 (similar to that shown in FIG. 9) between the funnel shaped gas distributor 416 and the feed 250. the slip-fit 258 is provided to accommodate the upward and downward movement of the process module 295 which open and close the process chambers of the various modules disclosed herein. The feed 250, which is an extension of tube 256, can be, as described above, a quartz tube which does not move as the reactor opens and closes. A bellows 414 encloses the slip-fit joint, to make it effectively gas-tight without requiring any sliding joint which might introduce particulates, but alternatively a slip-fit joint like that shown in FIG. 14 which is merely vented to the exhaust space could be used instead.

Detailed Description Text (203):
After the wafer is transferred onto fingers 214 by arm 28 and the arm is retracted, the fingers 214 are moved upward to clamp wafer 48 to susceptor 438. This is the position shown in FIG. 26B. While the wafer is in the horizontal position shown in

FIG. 26B, a cleanup operation can be performed, e.g. by flowing a CF.sub.4 plus O.sub.2 mixture through a remote plasma and also optionally providing ultraviolet illumination in situ from a plasma which is remote from the wafer face as discussed above.

Detailed Description Text (241):
As remote plasma processing is relatively new, prior methods of dealing with nonuniformity are few. One manufacturer has used a single showerhead with fairly large holes (about 0.25" i.d.) in two concentric circles, with one smaller hole (about 0.15" i.d.) in the center. Although this is an improvement over no showerhead, as another commercial photoresist stripper is set up, significant higher stripping rates still occur at the center of the wafer. The pattern of resist removal visibly copies the pattern of holes in the showerhead. A plot of resist removal across the wafer is shown in FIG. 30A. For comparison, results without any showerhead are shown in FIG. 30B.

Detailed Description Text (250):
Thus, this class of embodiments provides the following advantages: (1) application to all isotropic processing in fast flowing remote plasma systems, (2) promotion of uniform processing results, (3) maintenance of high reactant throughput for high rate of etching and deposition, (4) flexible materials choice for process compatibility, (5) comprehension of face-down processing.

Detailed Description Text (252):
One process disclosed herein provides a descum process which is a process for removal of polymers and other organic residues. The process uses a remote plasma, supplied through a distributor which includes a two-stage showerhead (FIG. 30C), to achieve improved results.

Detailed Description Text (254):
In one embodiment of this process, descum of patterned photoresist was successfully demonstrated using a process mixture of 1000 sccm O.sub.2, 200 sccm H.sub.2 at 100 C and 1 Torr total pressure. The choice of mass flows was set to result in high removal rate, proportional to O.sub.2 mass flow, but retaining uniform removal across the wafer which is inversely proportional to mass flow and pressure. The reactor is set up with all gases passing through a remote plasma chamber 254 powdered at 400 W.

Detailed Description Text (259):
A general problem with processes which use a remote plasma to generate activated species for etching or deposition applications is poor process uniformity across the surface of the wafer. This is a consequence of gas hydrodynamics which causes the formation of a boundary layer of stagnant gas just over the surface of the wafer. The stagnant gas hampers the transfer of reactants and products to and from the wafer. The problems are exemplified in photoresist ashing, where resist removal is typically several times higher immediately under the discharge tube's entrance to the reaction chamber than at the edge of the wafer. In this instance, the poor uniformity frustrates the use of such equipment for descumming applications. The teaching in the present application of using a specially designed two-stage showerhead will as a gas distributor in remote plasma applications provides the advantage of greatly improved uniformity.

Detailed Description Text (277):
The control systm 206 can be programmed to control any of the process operations performed, no matter which configuration of the vacuum processor is used. The control system 206 can establish the desired wafer temperature by one of several methods depending upon the configuration of the vacuum processor. In one case, where the vacuum processor utilizes a resistively heated substrate, the control system 206 is provided with temperature information from the heated substrate temperature sensor 720 and provides a control signal to the heated substrate

temperature controller 724 which controls the heated substrated power supply 725. In another embodiment, the control system provides an input to the radiant heat lamp power supply controller 721 which controls the amount of power and the rate of change of power input to the radiant heat lamps from the lamp power supply 722. In another embodiment, the control system 206 provides input to the heat exchanger control valves 723 which control the flow of cooling water to the substrate. In addition, when using a microwave plasma, the control system receives microwave plasma temperature information from the microwave plasma temperature sensor 726 and in turn sends a control signal to the microwave plasma power supply controller 727 which controls the microwave plasma power supply 728 to achieve proper plasma temperature.

Detailed Description Text (281):
When RF energy is used for generating a plasma or heating a substrate in the process chamber, the radio frequency temperature sensor provides a signal to the control system 206 corresponding to the temperature of the RF electrode in the process chamber. The control system provides a signal via the RF power supply controller 736 which in turn provides a signal to the RF power supply 737 that adjusts transmitter output power to achieve proper RF electrode temperature.

Detailed Description Text (289):
Referring to FIG. 32, a process module 1300 is shown. This process module has remote and in situ plasma. The wafer carrier 10, an arm (like arm 28) and chamber 12 are utilized to transfer the wafer 48 the carrier 10 to the process module 1300 is shown with a gas distributor 1302 attached to a gas distribution ring 1304 which is located in the upper part of top process chamber 1306. The gas distributor 1304 supplies the gas for the in situ plasma through the ring 1304. The ring 1304 is arranged about the vertical axis of the chamber 1306. The exits from ring 1304 through a plurality of openings 1310 in the bottom of ring 1304. The vertical walls of chamber 1306 can be made of quartz and form a cylinder about the vertical axis of chamber 1306. The bottom of chamber 1306 is an electrode 1312. The top of chamber 1306 in the closed position (as shown in FIG. 31) is an electrode 1314. A heat exchanger (not shown) can be provided for electrode 1314, if desired, for example, to maintain an ambient temperature of, for example, 25 degrees C.

Detailed Description Text (291):
The remote plasma is supplied into the bottom of chamber 1306 along the vertical axis through a pipe 1322. Pipe 1322 extends fom a remote plasma generator 1326 and through electrode 1312 into chamber 1306. The pipe 1322 has a slip fit 1328 with electrode 1312 to accommodate the vertical movement of chamber 1306 including the electrode 1312. Below electrode 1312 is located a chamber 1330 which is connected to pump 1332 and valve 1334. Thus a generally downwardly flow of gas through chambers 1306 and 1330 is provided. The in situ plasma is provided by the application of appropriate voltages between electrodes 1312 and 1314. The voltage would be RF to provide the desired excitation to the gas in chamber 1306. Pump 1332 and valve 1334 provide the desired vacuum within chamber 1306. This the remote plasma from generator 1326 and the in situ plasma generated within the chamber 1306 are joined in acting on face 54. The distributor 1302 also has a slip fit with electrode 1312. Distributor 1302 extends along the vertical wall of chamber 1306. The process module 1300 is adapted to perform various processes.

Detailed Description Text (292):
One process which has been successfully used with the process modules having both remote and in situ plasma is etching of silicon doped aluminum, for example, aluminum doped with 1% of silicon. A synergistic etch rate enhancement of more than double the sum of their individual etch rates was obtained for combined microwave and RF etching under the following conditions: gas flows were 80 sccm BCl.sub.3 plus 20 sccm Cl.sub.2 plus 1000 sccm He, at 1 Torr total pressure, 225 W RF Power (applied to generate a plasma near the face of the wafer) at a frequency of 13.56 MHz and 400 W microwave power at a frequency of 2450 MHz. The temperature used was

an ambient temperature of about 25 degrees C. These results were obtained even though they are based on etch rates which were not very high since the flows had not been optimized for the particular conditions used, but they do show the synergistic advantage of combining these two effects. The gas mixture can all be introduced from pipe 1322 into chamber 1306 or a part of the gas mixture including other gas not mentioned above, can be introduced through ring 1304. Further, a source of hydrocarbon, for example, methane could introduced through ring 1304 or the methane could be a part of the remotely generated plasma.

Detailed Description Text (293):
Another process useful with process module 1300 is for the deposition of Polysilicon. A gas mixture of an inert gas and a source of silicon, for example, SiH.sub.4 and/or Si2H6 is used with remote plasma and in situ plasma to produce improved deposition rate over the sum of the rates of in situ and remote plasmas used separately. As an example, the RF power is 100 watts in the process chamber at an 13.56 MHz and the remote plasma generator is operating at 400 watts at 2450 MHz. The gases are Helium at 1000 sccm and SiH.sub.4 at 50 sccm. Argon is another example of an inert gas which can be used. The pressure can be 1 Torr and the temperature 25 degrees C. The SiH.sub.4 is introduced into the process chamber through ring 1304 and remaining gas passes through the generator 1326. The results were obtained even though they had not been optimized for the particular conditions used, but they do show the synergistic advantage of combining these two effects. Surface damage can be reduced by increasing the pressure to greater than 1 Torr. This process results in improved results because of a synergistic effect between the remote and in situ plasmas. The surface damage is minimized while the deposition rate is improved. The remote and in situ plasmas can be separately controlled. This process can be used with silicon, GaAs, and HgCdTe substrates.

Detailed Description Text (294):
Another process useful with process module 1300 is for the deposition of silicon oxide. A gas mixture of Helium, O.sub.2, and SiH.sub.4 is used with remote plasma and in situ plasma to produce improved deposition rate over the sum of the rates of in situ and remote plasmas used separately. As an example, the RF power is 100 watts in the process chamber at an 13.56 MHz and the remote plasma generator is operating at 400 watts at 2450 MHz. The gases are Helium at 1000 sccm, O.sub.2 at 100 sccm, and SiH.sub.4 at 50 sccm. The pressure can be 1 Torr and the temperature 25 degrees C. The SiH.sub.4 is introduced into the process chamber through ring 1304 and remaining gas passes through the generator 1326. Surface damage can be reduced by increasing the pressure to greater than 1 Torr. The temperature can be within the range of 25 to 400 degrees C. This process results in improved results because of a synergistic effect between the remote and in situ plasmas. These results were obtained even though they had not been optimized for the particular conditions used, but they do show the synergistic advantage of combining these two effects. The surface damage is minimized while the deposition rate is improved. The remote and in situ plasmas can be separately controlled. This process can be used with silicon, GaAs, and HgCdTe substrates.

Detailed Description Text (295):
Another process useful with process module 1300 is for the deposition of silicon nitride. A gas mixture of Helium, one of a group of N.sub.2 and NH.sub.3, and one of a group SiH.sub.4 or SiH.sub.2 Cl.sub.2 is used with remote plasma and in situ plasma to produce improved deposition rate over the sum of the rates of in situ and remote plasmas used separately. As an example, the RF power is 100 watts in the process chamber at an 13.56 MHz and the remote plasma generator is operating at 400 watts at 2450 MHz. The gases used were Helium at 1000 sccm, one of a group of N.sub.2 and NH.sub.3 at 100 sccm, and one of a group SiH.sub.4 or SiH.sub.2 Cl.sub.2 at 50 sccm. The pressure can be 1 Torr and the temperature 25 degrees C. The SiH.sub.4 or SiH.sub.2 Cl.sub.2 is introduced into the process chamber through ring 1304 and remaining gas passes through the generator 1326. Surface damage can be reduced by increasing the pressure to greater than 1 Torr. The temperature can

be within the range of 25 to 400 degrees C. This process results in improved results because of a synergistic effect between the remote and in situ plasmas. These results were obtained even though they had not been optimized for the particular conditions used, but they do show the synergistic advantage of combining these two effects. The surface damage is minimized while the deposition rate is improved. The remote and in situ plasmas can be separately controlled. This process can be used with silicon, GaAs, and HgCdTe substrates.

Detailed Description Text (296):
Another process useful with process module 1300 is for the etch of GaAs A gas mixture of Helium, CH.sub.4, and one of a group of CF.sub.4 or F.sub.2 is used with remote plasma and in situ plasma to produce improved etch rate over the sum of the rates of in situ and remote plasmas used separately. As an example, the RF power is 100 watts in the process chamber at an 13.56 MHz and the remote plasma generator is operating at 400 watts at 2450 MHz. The gases used were Helium at 1000 sccm, CH.sub.4 at 250 sccm, and CF.sub.4 or F.sub.2 at 100 sccm. The pressure can be 1 Torr and the temperature 25 degrees C. The CH.sub.4 is introduced into the process chamber through ring 1304 and remaining gas passes through the generator 1326. This process results in improved results because of a synergistic effect between the remote and in situ plasmas. These results were obtained even though they had not been optimized for the particular conditions used, but they do show the synergistic advantage of combining these two effects. The surface damage is minimized while the etch rate is improved. The remote and in situ plasmas can be separately controlled. The resultant etch is partially anisotropic. The level of anisotropy can be controlled by the relative RF plasma and microwave power levels, as well as the pressure.

Detailed Description Text (297):
Another process useful with process module 1300 is for the etch of ZnS or HgCdTe which form at least a part of a wafer. A gas mixture of a source of atomic fluorine mixed with a inert carrier such as Helium is utilized to generate a remote plasma. An in situ plasma is generated from at least the products of the remote plasma and an alkyl-bearing species. The powers used to generate the remote plasma and in situ plasma are separately controlled to produce improved etch rates. The remote and in situ plasmas produce an etch rate which is greater than the sum of the rates of in situ and remote plasmas used separately. Relative low power RF is used to generate an in situ plasma in conjunction with the remote plasma to provide an partially anisotropic etch with a relative high etch rate. Since the remote plasma and in situ plasma can be separately controlled, improved profile control and etch selectivities can be achieved. An in situ descum can be performed before the etch and a post-etch ashing utilizing a remote plasma formed from a source of oxygen. The alkyl-bearing process can be, for example, methane, ethane, mehtylfouoride, methylchlorides, methyliodide, or methylbromide. The source of atomic fluorine can be, for example, fluorine, CF.sub.4, SF.sub.6, NF.sub.3, C.sub.2 F.sub.6 or any other gaseous fluorine compound which releases its fluorine atoms in the presence of a plasma. The power used can be, for example, 250 watts or less for the RF and 400 watts for the MW. The flow rates can be 100 sccm for CF.sub.4, 125 sccm for Ch.sub.4, and 1000 sccm for Helium. The pressure can be, for example, 0.8 Torr. The surface damage is minimized while the etch rate is improved. The remote and in situ plasmas can be separately controlled. The resultant etch is partially anisotropic. The level of anisotropy can be controlled by the relative RF plasma and microwave power levels, as well as the pressure.

Detailed Description Text (298):
Another process useful with process module 1300 is for the ashing of photoresist. A gas mixture of Oxygen and an ashing enhancement gas, for example, one or more of the group of CF.sub.4, CHF.sub.3, H.sub.2, H.sub.2 O, HCl, HBr, Cl.sub.2, and N.sub.2 O, is used with remote plasma and in situ plasma to produce improved ashing rate over the sum of the rates of in situ and remote plasmas used separately. As an example, the RF power is 225 watts in the process chamber at an 13.56 MHz and the

remote plasma generator is operating at 400 watts at 2450 MHz. The gasses used were CF.sub.4 at 43 sccm and Oxygen at 996 sccm. The pressure can be 0.63 Torr and the temperature 25 degrees C. All of the gas can be passed through the remote plasma generator 1326. This process results in improved results because of a synergistic effect between the remote and in situ plasmas. These results were obtained even though they had not been optimized for the particular conditions used, but they do show the synergistic advantage of combining these two effects. The surface damage is minimized while the ashing rate is improved. The remote and in situ plasmas can be separately controlled. The resultant ashing is partially anisotropic. The level of anisotropy can be controlled by the relative RF plasma and microwave power levels, as well as the pressure.

Detailed Description Text (299):
Another process useful with process module 1300 is for the etch of Silicon Nitride. A source of Fluorine and Helium were used with remote plasma and in situ plasma to produce improved etch rate over the sum of the rates of in situ and remote plasmas used separately. As an example, the RF power is 225 watts in the process chamber at an 13.56 MHz and the remote plasma generator is operating at 400 watts at 2450 MHz. The gases used were fluorine gas source, for example, CF.sub.4 at 200 sccm and Helium at 1000 sccm. Other sources of Fluorine can be F.sub.2, CHF.sub.3, C.sub.2 F.sub.6, SF.sub.6, or F.sub.3, singly or in any combination with CF.sub.4. The pressure can be 0.7 Torr and the temperature 25 degrees C. This process results in improved results because of a synergistic effect between the remote and in situ plasmas. These results were obtained even though they had not been optimized for the particular conditions used, but they do show the synergistic advantage of combining these two effects. The surface damage is minimized while the etch rate is improved. The remote and in situ plasmas can be separately controlled. The resultant etch is partially anisotropic. The level of anisotropy can be controlled by the relative RF plasma and microwave power levels, as well as the pressure.

Detailed Description Text (300):
A further process useful with process module 1300 is for the etch of polysilicon. A source of Fluorine and Helium were used with remote plasma and in situ plasma to produce improved etch rates of twice the sum of the remote and in situ plasmas alone. As an example, the RF power is 225 watts in the process chamber at an 13.56 MHz and the remote plasma generator is operating at 400 watts at 2450 MHz. The gases used were fluorine gas source, for example. CF.sub.4 at 200 sccm and Helium at 1000 sccm. Other sources of Fluorine can be F.sub.2, CHF.sub.3, C.sub.2 F.sub.6, SF.sub.6, or NF.sub.3 singly or in any combination with CF.sub.4. The pressure can be 0.7 Torr and the temperature 25 degrees C. This process results in improved results because of a synergistic effect between the remote and in situ plasmas. These results were obtained even though they had not been optimized for the particular conditions used, but they do show the synergistic advantage of combining these two effects. The surface damage is minimized while the etch rate is improved. The remote and in situ plasmas can be separately controlled. The resultant etch of the polysilicon is partially anisotropic. The level of anisotropy can be controlled by the relative RF plasma and microwave power levels, as well as the pressure.

Detailed Description Text (301):
Another process which utilizes remote and in situ plasmas is the etching of copper doped aluminum films. The process is carried out in, for example, module 1300 or module 680 of FIG. 24. A source of Chlorine, which can be, for example, Cl.sub.2, CCl.sub.4, or SiCl.sub.4, a source of hydrocarbon, for example, CH.sub.4, and BCl.sub.3 are used. The hydrocarbon can be omitted but a line width loss will occur. As an example, the RF power applied between the electrodes within the process chamber can be about 250 watts at 13.5 MHz. The remote plasma generator can be power at 400 watts with a frequency of 2450 MHz. The pressure with the process chamber, for example, chamber 1306 (FIG. 31) can be 0.15 Torr. The temperature within the process chamber can be at an ambient temperature, for example, about 25 degrees C. The gases used can be BCl.sub.3 at 80 sccm, Cl.sub.2 (chlorine) at 10

sccm, and a hydrocarbon source, for example, CH.sub.4 (methane) at 5 sccm. These results were obtained even though they are based on etch rates which were not very high since the flows had not been optimized for the particular conditions used, but they do show the synergistic advantage of combining these two effects. The gas from the gas distributor 1302 and the pipe 1322 can be the same or different as desired. This process allows the resultant etched surfaces to have reduced residues, for example, Copper Chloride. The etch is enhanced by the use of both remote and in situ plasma. This allows lower RF power to be used which reduces surface damage and maintains the integrity of the photoresist. The pressure should be from less than slightly above 1 Torr to less than one Torr.

Detailed Description Text (302):
Another useful process is an overetch of a tungsten material (a layer) to achieve selectivity to silicon dioxide and the desired anisotropy. A source of Fluorine, which can be, for example, CF.sub.4, C.sub.2 F.sub.6, HF, F.sub.2, NF.sub.3, or SF.sub.6, a source of hydrocarbon, for example, CH.sub.4 and HBr are used. The hydrocarbon and HBr can be omitted but an improved etch is provided if they are present. The hydrocarbon performs a side wall passivant during the etch which reduces the line width loss. As an example, first, the bulk of the tungsten layer is etched using, for example, one of the tungsten etch processes discussed herein. After this step, the etching continues utilizing remote and in situ plasma under the following conditions as an example. The RF power is 50 watts in the process chamber at an appropriate frequency and the remote plasma generator is operating at 400 watts. The gases can be a fluorine gas source, for example, SF.sub.6, at 40 sccm, a bromine source, for example, HBr at 13 sccm, and a hydrocarbon source, for example, CH.sub.4 (methane) at 5 sccm. The pressure can be 0.13 Torr and the temperature 25 degrees C. This process results in improved results because of a synergistic effect between the remote and in situ plasmas which provides an increased selectivity to silicon dioxide and photoresist. The etch is also improved by allowing the separate adjustment of microwave (MW) and radio frequency (RF) power during the plasma generation. The pressure should be from about 0.1 Torr to about 5 Torr.

Detailed Description Text (313):
Another process which is adapted for use with process module 1300 is a low pressure silicon nitride etch. This etch utilizes a remote plasma gas mixture of SF.sub.6 flowing at 100 sccm and He flowing at 5000 sccm. The substrate has a temperature of 25 degrees C., RF plasma was not generated. The etch rate of the silicon nitride was 37 angstroms per minute. The silicon dioxide was observed not to have etched. An addition source of Fluorine could be used such as F.sub.2, CF.sub.4, or C.sub.2 F.sub.6. These additional sources may reduce the selectivity of the etch to silicon oxide. The etch rate can be increase by the additional use of RF in situ plasma. This process is also useful for GaAs and HgCdTe processing.

Detailed Description Text (314):
In another process, after one of the tungsten etches described above has etched most of the tungsten film the present process is utilized to provide an etch which is both anisotropic and selective to silicon dioxide and photoresist by utilizing both remote and in situ plasmas. The gas mixture used was comprised of SF.sub.6 at 40 sccm, HBr at 13 sccm, and a source of hydrocarbons, for example, CH.sub.4 (methane) at 5 sccm. The pressure and temperature used were 0.13 Torr and 25 degrees (ambient) C., respectively. The RF and W power used to produce the in situ and remote plasmas were 40 and 400 watts, respectively. The in situ and remote plasmas produce a synergistic effect which results in improved etch characteristics, including selectivity and anisotropy. This includes the separate control of the generation of the remote and in situ plasmas.

Detailed Description Text (321):
A process module 2000 is shown in FIG. 37. Many of the components of process module 2000 as similar to the components of other modules discussed above. The carrier 10

and chamber 12 operate as discussed above in connection with FIGS. 1, 3, and 4 above. The wafer 48 is shown is with in carrier 10 at its leftmost position and in transit within chamber 12 in its middle position. The type of particle control discussed above in connection with FIG. 11 can be used with module 2000 and the other modules disclosed herein. Wafer 48 in its rightmost position is disposed within a process chamber 2002. A remote plasma generator 2010 generates a remote plasma using microwave energy from the gas mixture supplied through pipe 2012. The feed 250 provides the remote plasma from generator 2010 to chamber 2002. Pipes 2020 and 2022 are connected through a vacuum connection to ultraviolet space 2024 and chamber 2002, respectively. Pipes 2020 and 2022 are connected to gas distribution rings 2026 and 2028, respectively. Space 2024 is located below chamber 2002. A quartz baffle 2030 separates spaces 2024 from chamber 2002. The feed 250 has a slip-fit with quartz baffle 2030. The quartz baffle 2030 has a basic H-shape in cross-section with feed 250 passing through the center of the crossbar. Ring 2026 is located with space 2024 and ring 2028 is located within chamber 2002.

Detailed Description Text (329):
In FIG. 39, an electrode 2310 is located between wafer and plate 2052. The plate 2052 is conductive and can be made of, for example, graphite or silicon. Conductor 2312 is attached to electrode 2310 near its edge. Fingers 2260 bring wafer 48 into contact with electrode 2310 when the chamber 2002 is closed as shown in FIG. 39. It should be noted that the fingers 2260 have a notch 2330 which allows the wafer to lie in the notch with the upper ends of the fingers to rest against plate 2052 with the wafer held against electrode 2310, or as shown in FIG. 38, against plate 2054. However, the pins 53 in FIGS. 1, 3, and 4 could also be used. The heat from module 2050 is directed onto electrode 2310 except at the circumference of wafer 48 by surface 2290 directing heat toward axis 2120. The sensors 2246 also provide the same function of providing the temperature of the wafer at various locations, for example, adjacent the circumference, at about one half of the radius, and adjacent the center. This arrangement allows the use of in situ plasma. The RF power would be applied to electrode 2310 and cylindrical support 2311. This would allow the RF enhanced plasma as discussed above to be utilized for the above described processes and for chamber cleanup as described above.

Detailed Description Text (331):
Unless specifically stated otherwise above the power and frequencies used for RF and MW plasma and ultraviolet light can be widely varied, as can the other process parameters. The term low pressure as used herein indicates a pressure which is less than ambient pressure.

Detailed Description Text (332):
All of the process modules disclosed herein can be utilized with one or more of the chamber 12 and arm 28 as shown in FIGS. 1, 3, 4, 5A, and 5B. Although silicon, GaAs, and HgCdTe examples are shown herein wafers made of other materials such as germanium, etc. can be utilized. The wafers can be comprised of many different configurations, for example, a single piece of crystal material or small crystals located on a larger substrate. The plasma produced as disclosed herein will include free radicals. Although wafers such as wafer 48 are disclosed herein other types of flat workpieces could be used with the techniques disclosed herein.

Detailed Description Text (335):
It is an advantage of the present invention to provide a module that has separate energy sources for internal remote MW (Microwave) plasma generation, RF in situ plasma generation, and radiant heat applied to the same process chamber within the module.

Detailed Description Text (336):
It is an advantage of the present invention to provide a module that has separately controllable energy sources for internal remote MW (Microwave) plasma generation, RF in situ plasma generation, and radiant heat.

Detailed Description Text (337):
It is an advantage of the present invention to provide a module that has separate energy sources for internal remote MW (Microwave) plasma generation, RF in situ plasma generation, and radiant heat, which can be used singly or in any combination.

Detailed Description Text (339):
It is an advantage of the present invention to provide dry in situ cleanup with remote and in situ plasma.

Detailed Description Text (342):
It is an advantage of the present invention to provide a process module capable of low temperature epitaxial film growth with remote MW (Microwave) plasma source combined with radiant heat.

Detailed Description Text (344):
It is an advantage of the present invention to provide a process module with higher dry etch rates and higher selectiveness, including isotropic and anisoptropic processes, by using in situ RF and remote MW plasma in combination.

Detailed Description Text (347):
It is an advantage of the present invention to provide a process module with higher dry etch rates and higher selectiveness by using in situ RF, remote MW plasma, and radiant head in any combination.

Current US Cross Reference Classification (6):
438/905

Other Reference Publication (1):
Lucovsky et al., "Deposition of Dielectric Films by Remote Plasma Enhanced CVD", Mat. Res. Soc. Symp. Proc., vol. 68, 1986, pp. 323-334.

CLAIMS:

1. A vacuum process module capable of receiving a workpiece comprising:

(a) a process chamber;

(b) a remote plasma generator remote from and in fluid communication with said process chamber;

(c) an in situ plasma generator within said process chamber; and

(d) a radiant heater coupled to said process chamber.

6. The module as set forth in claim 1 wherein said in situ plasma generates a plasma below said workpiece and said in situ plasma generator has electrodes above and below said workpiece.

7. The module as set forth in claim 1 wherein the plasma from said remote plasma generator is introduce to the surface from below said workpiece.

9. A vacuum process module capable of receiving a workpiece comprising:

(a) a plasma generator generating at least free radicals remote and in fluid communication with the workpiece; and

(b) a heater coupled to said workpiece.

14. The module as set forth in claim 9 wherein the plasma from said remote plasma generator is introduce to the surface from below said workpiece.

16. A vacuum process module capable of receiving a workpiece comprising:

(a) an in-situ plasma generator coupled to said workpiece; and

(b) a heater coupled to said workpiece.

22. The module as set forth in claim 16 wherein said in situ plasma is generated below said workpiece and said in situ plasma generator has electrodes above and below said workpiece.

23. A vacuum process module capable of receiving a workpiece comprising:

(a) a plasma generator for generating free radicals remote from and in fluid communication with said workpiece; and

(b) at least a first energy source coupled to said workpiece.

24. The module as set forth in claim 23 wherein said first energy source is an in situ plasma generator.

28. The module as set forth in clalm 23 wherein said plasma generator and said first energy source are separately controlled to operate singly.

29. The module as set forth in claim 23 wherein said plasma generator and said first energy source are separately controlled to operate in any combination.

32. The module as set forth in claim 24 wherein said in situ plasma is generated below said workpiece and said in situ plasma generator has electrodes above and below said workpiece.

33. A vacuum process module comprising:

(a) a process chamber;

(b) a plasma generator remote from and in fluid communication with said process chamber; and

(c) at least a first energy source within said process chamber.

34. The module as set forth in claim 33 wherein said first energy source is an in situ plasma generator.

37. The module as set forth in claim 33 wherein said plasma generator and said first energy source are separately controlled to operate singly.

38. The module as set forth in claim 33 wherein said plasma generator and said first energy source are separately controlled to operate in any combination.

39. A vacuum process module capable of receiving a workpiece comprising:

(a) a remote plasma generator in fluid communication with said workpiece;

(b) an in situ plasma generator coupled to said workpiece; and

(c) a heater coupled to said workpiece.

45. The module as set forth in claim 39 wherein said in situ plasma is generated

below said workpiece and said in situ plasma generator has electrodes above and below said workpiece.

46. The module as set forth in claim 39 wherein the plasma from said remote plasma generator is introduce to the surface from below said workpiece.

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